CASE STUDY REPORT #2
SHASTA DAM (INCLUDING KESWICK DAM)
SACRAMENTO RIVER

I. Project Description

Shasta Dam impounds and regulates the flow of the Pit River, McCloud River, Sacramento River and numerous creeks which originate in its 6,700 square mile watershed. It is the largest storage reservoir in the California Central Valley Project with a gross storage of over 4.5 million acre-feet and it covers a maximum surface area of 29,500 acres. The water released from Shasta is reregulated nine miles downstream by Keswick Dam. Both dams are operated by the Bureau of Reclamation as a multipurpose project to provide flood control, irrigation, navigation, fish and wildlife conservation, hydroelectric power, recreation and salinity control in the Sacramento-San Joaquin River Delta. Claire Engle Lake on the Trinity River and Whiskeytown Reservoir on Clear Creek are integral parts of the Shasta-Keswick system with the diversion of water from the Trinity River into Keswick Reservoir. The locality of these reservoirs and their interrelationship can be seen in Figure 1.

Construction began in 1938 and was generally completed in 1945. Shasta power plant went into full operation in 1949, when the last of the generators was installed.

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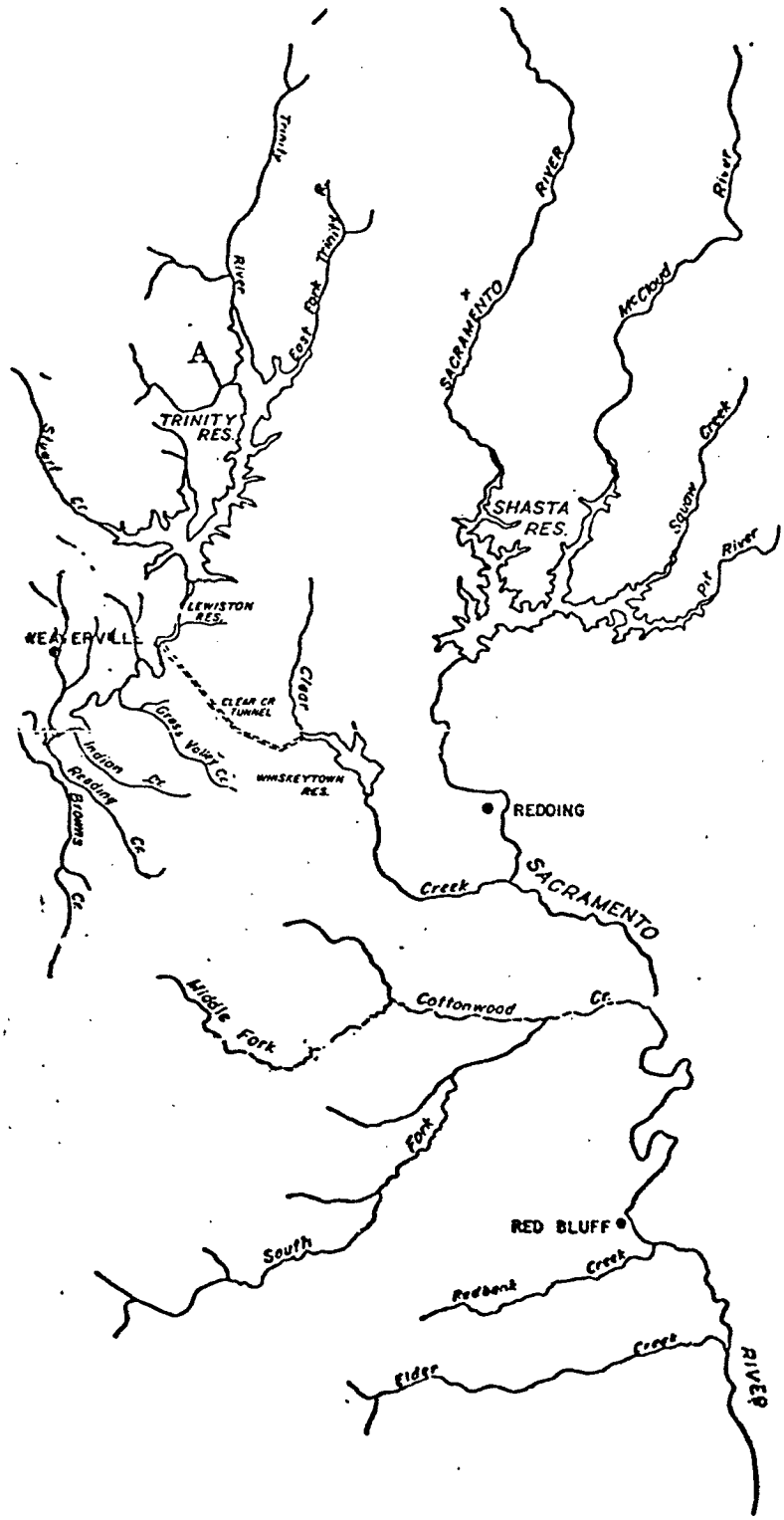
Figure 1
LOCATION MAP



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Diurnal fluctuations in discharge, resulting from power production in the Shasta power plants, are reregulated by Keswick Dam and power plant to cause modulated flows past Redding. Keswick Reservoir was completed in 1950, and it has a maximum storage capacity of 24,000 acre-feet covering 640 acres. Since 1963, Keswick Dam releases have been influenced by an annual average discharge of 2,200 cubic feet per second (cfs) into Keswick Reservoir from Spring Creek power plant. This water is released from Whiskeytown Lake by way of a tunnel to the Spring Creek power plant (see Figure 1).

The Bureau of Reclamation operators of the Shasta-Keswick unit of the Central Valley Project also in coordination with the U. S. Fish and Wildlife Service operate facilities to maintain a portion of the Sacramento River king salmon and steelhead fisheries, i.e., the Coleman Hatchery and Keswick Fish Trapping Facilities.

Winter run king salmon migrating up the Sacramento River to spawn are trapped at Keswick Dam and lifted by a fish elevator to a waiting tank truck. They are then transported 30 miles downstream to the Coleman Hatchery for spawning and rearing.

Coleman Hatchery, completed in 1943, has the capacity to hatch 58 million eggs while its rearing facility can support 15 million juvenile fish three inches in length. Steelhead smolts and juvenile salmon are released into Battle Creek and the Sacramento River.

II. Pre-Project Conditions

Prior to the construction of Shasta Dam, the Sacramento, Pit and McCloud Rivers joined about 10 miles upstream from the dam site. The upper Sacramento River above the mouth of the Pit River was a comparatively small stream, but enlarged considerably with inflows from the Pit and McCloud Rivers. The natural stream flow displayed a large seasonal variation with practically all of the annual discharge occurring during the winter and spring months (see Figure 2).

The most economically important fish in the upper Sacramento River were the king salmon and a few steelhead and sturgeon that historically used the spawning and rearing grounds in the major tributary streams above the present dam site. Historically (circa 1879), the upper Sacramento and McCloud Rivers were considered the principal spawning streams of the main Sacramento River king salmon run. This situation began to change in later years and is explained by Clark (1929): "Before the Southern Pacific Railroad was put through the Sacramento Canyon, the salmon were extremely abundant, but during the construction work, the run was almost destroyed".

In 1938, the potential spawning capacity was estimated to be 14,303 nests (Hanson, et.al., 1940). As a result of pre-project surveys conducted by the U. S. Fish and Wildlife Service above and below the present dam site, it was concluded that 40 percent of the spawning grounds available to salmon in the

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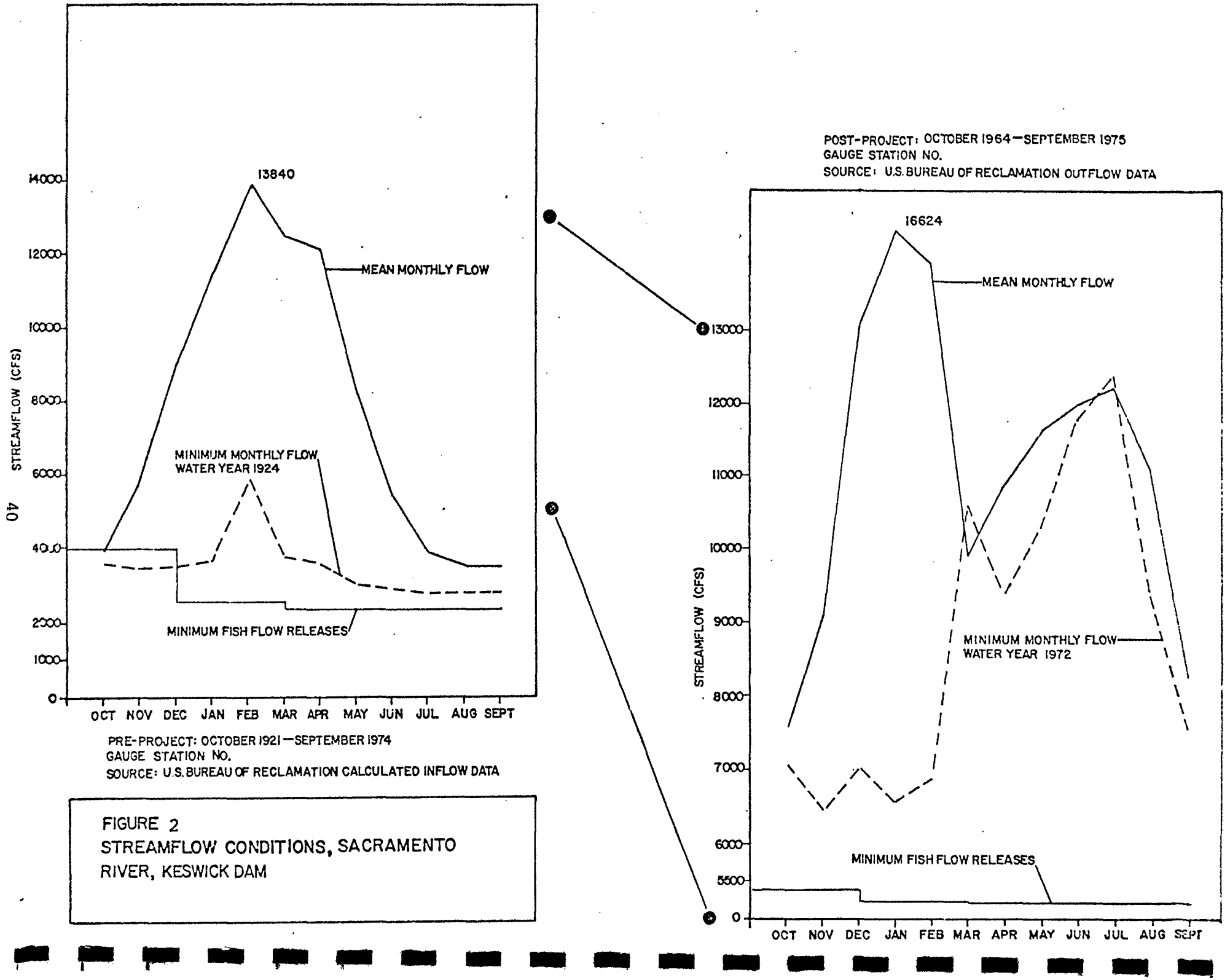

FIGURE 2
STREAMFLOW CONDITIONS, SACRAMENTO RIVER, KESWICK DAM

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Sacramento River would be eliminated by construction of Shasta Dam (Hanson, Smith and Needham, 1940). Later surveys have shown that the spawning grounds above the dam site constituted an estimated 50 percent of those available to Sacramento River basin salmon (Moffet, 1949).

Pre-project conditions in the Sacramento River near the present Keswick dam site were described by the U. S. Fish and Wildlife Service (1950) as a typical lowland river of the Central Valley. In summer months, the characteristic low flows and warm temperatures provided habitat for warmwater species of fish. The most common fish supported by this section of river during low flow periods of the year were catfish, largemouth bass, bluegill, Sacramento squawfish, and Sacramento sucker. Seasonal fisheries during spawning runs were supported by king salmon, steelhead, striped bass, American shad and occasional white sturgeon (U. S. Fish and Wildlife Service, 1950).

The main Sacramento River salmon fishery was once a major industry in California. In 1882, 21 canneries were in operation and 12,000,000 pounds of fish were taken from the Sacramento River. King salmon and steelhead trout were found in the Sacramento River during their spawning migrations in the fall, winter and early spring. Two well identified king salmon runs passed up the Sacramento -- one in spring and one in fall. Evidence of a small winter run was found on the

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McCloud River during stream surveys in 1938 (Hanson, et.al., 1940). The steelhead trout fishery was quite constant beginning in the fall and lasting until late February; however, the run was minor compared to king salmon.

The spring spawning run of king salmon suffered serious depletion from 1917 to 1927 due to the installation of the Anderson-Cottonwood Irrigation District (ACID) diversion dam near Redding. This dam was a temporary structure used only during the irrigating season, but it was a partial barrier to spring run salmon until 1927 when a fish ladder was installed at the insistence of the State of California. In the following years, the spring run increased (Moffet, 1949).

The first record of salmon counts at the ACID dam fish ladder was in 1937 when the Department of Fish and Game counted 7,780 salmon from August 1 to October 15. In 1938 the Bureau of Reclamation began a count at the dam as part of a study to assess the effect of Shasta Dam on the salmon fishery. In 1939 the U. S. Fish and Wildlife Service took over the study and the count.

Beginning in 1938 a counting weir was installed at the dam and 13,855 fish were counted from September 2 to November 2. In 1939 a more complete count was attempted. The results of the 1938 counts and the 1940 count are shown on Table 1. Attempts were made in 1941 and 1942 to continue the salmon count while the dam was in place during the irrigating season, but usually high water prevented accurate counts. The number of other fish

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Table 1

Weekly Counts of Salmon at Anderson-Cottonwood Dam, Redding, 1937-1940

Week ending	1940	1939	1938	1937
April 23	.....	164	.....	.....
April 30	.....	224	.....	.....
May 7	.....	119	.....	.....
May 14	.....	681	.....	.....
May 21	585	983	.....	.....
May 28	1,709	488	.....	.....
June 4	1,645	697	.....	.....
June 11	3,075	633	.....	.....
June 18	2,456	623	.....	.....
June 25	344	395	.....	.....
July 2	160	219	.....	.....
July 9	62	297	.....	.....
July 16	129	56	.....	.....
July 23	129	28	.....	.....
July 30	745	39	.....	.....
August 6	289	95	.....	.....
August 13	82	7	.....	13
August 20	238	19	.....	7
August 27	38	15	.....	3
September 3	108	6	6 (c)	16
September 10	315	96	21	35
September 17	806	625	38	114
September 24	.....	1,641	64	175
October 1	.....	1,591	168	967
October 8	.....	1,077	912	1,172
October 15	.....	1,754	1,394	5,280
October 22	.....	2,731	2,054	..... (f)
October 29	.....	2,497	8,174	.....
November 5	.....	1,258	1,054 (d)	.....
November 12	.....	680	..... (e)	.....
November 19	.....	1,418	.....	.....
November 26	.....	302 (b)	.....	.....
December 3	.....	286	.....	.....
December 8	.....	150	.....	.....
TOTALS	12,906	21,894	13,885	7,781

(a) and (b) Total for 6 days.
(c) Total for 1 day.
(d) Total for 5 days.
(e) 5,500 additional fish estimated as passing dam site.
(f) 10,900 fish estimated October 16 to October 23.

Source: Hanson, et.al., 1940.

COUNTS OF FISH OTHER THAN SALMON AT ANDERSON COTTONWOOD DAM, 1939

Season	Sucker	Squawfish	Carp	Shad	Sheelhead	Brown Trout
Spring (Apr. 17-Sept. 1)	2,525	55	4	11	36	0
Fall (Sept. 1-Dec. 8)	0	0	0	0	82	114

Source: Needham, et.al., 1953.

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species besides king salmon passing through the counting weir in 1939 are presented in Table 1 (bottom half, as provided by Needham, et.al., 1953).

None of these counts can be used to estimate the winter run of salmon or other fish before the dam. Although salmon and steelhead populations had declined from their historical levels, the continued year-round runs were very large and supported large fisheries in the ocean, Delta and river.

III. Project Development

Shasta Dam was the first Bureau of Reclamation Central Valley Project reservoir. Concurrent projects were the Contra Costa Canal, which starts at Rock Slough in the Sacramento River Delta and supplies water to Contra Costa County, and the Delta Mendota Canal which conveys San Joaquin water into the San Joaquin Valley.

The plan for a large dam on the Sacramento River had been in print since 1931 (Bulletin 26, California State Water Plan, Sacramento River Basin). Requests for bids were sent out to the contractors in 1938 and construction began in September of that year.

It was not until shortly before June 1938 that a study was initiated by the Bureau of Reclamation to assess the probable effects of Shasta Dam on fisheries resources in the Sacramento River. It had originally been expected that the dam would become impassable in late 1941, although this schedule provided three

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years to conduct a biological investigation and devise a plan for preservation of the anadromous fisheries resources of the Sacramento River. The salmon maintenance plan devised by the study was not placed into operation until June 1, 1943. Wartime conditions caused the delay of the program and general lack of adequate facilities and equipment (Moffet, 1949).

The Sacramento River fisheries study, supported by funds from the Bureau of Reclamation, was taken over by the U. S. Fish and Wildlife Service in 1939. The U. S. Fish and Wildlife Service presently acts as the Bureau's agent in studying and operating the fish maintenance program of the Shasta project.

To evaluate the Shasta project, the Fish and Wildlife Service undertook a broad study of Sacramento Valley streams in 1939. Also during this time, the California Department of Fish and Game conducted a Central Valley fisheries investigation (Hatton, 1940) which contributed to the Shasta study. All the important tributaries above Shasta dam site and downstream as far as the City of Sacramento were surveyed through the efforts of these two fisheries agencies. The purpose of these pre-project surveys was to determine the extent of the spawning grounds to be lost by blockage of the river at Shasta Dam and to investigate the feasibility of transferring the upper Sacramento River salmon run affected by the dams to downstream tributaries of the Sacramento River. The results of this study was published as a summary in 1940 (Needham, Smith and Hanson, 1940). The major conclusions of the investigation were:

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1. An annual run of 27,000 fish will be blocked by the dam.
2. A fish ladder over Shasta Dam is impracticable.
3. From among the tributaries of the Sacramento River below Shasta that were examined, only two streams, Battle and Deer Creek, were found to be feasible for sustaining a transferred salmon run.
4. Not a single effective fish screen was found on any of the diversions investigated, and most of the fish ladders seen were inoperable because of lack of water.
5. Copper pollution in the Sacramento River above Redding from abandoned mines may become lethal to trout and salmon unless corrective measures are undertaken.

This study indicated that there were several downstream problems that needed correction in addition to those caused directly by the dam.

The results of the study were submitted as a preliminary biological report in 1940 (Hanson, Needham and Smith). This report proposed several plans for "salmon salvage" and was presented for review to a Board of Consultants appointed by the Bureau of Reclamation. Professor R. D. Calkins, Professor W. F. Durand and Professor Willis H. Rich, members of the Board, recommended what was known as the Sacramento River, Battle Creek,

Deer Creek Plan. The selected plan placed in operation on June 1, 1943 included the following essential features:

1. The spring run and early fall run of king salmon would be transferred by trucks to Battle and Deer Creeks because of the high water temperature expected to occur in the Sacramento River at those times of the year.

2. Construct three rack barriers across the Sacramento River between the present Keswick dam site and the mouth of Battle Creek during the fall salmon run. The expectation was that these racks would prevent overcrowding below the dam and promote natural spawning in the river.

3. Coleman Hatchery was to be constructed on Battle Creek.

The report issued by the Board of Consultants in June 1940 set forth conclusions regarding the king salmon run on the upper Sacramento River. It was concluded that:

> "(1) There are two salmon runs at Redding, California, a spring run, comprising five or six thousand fish, and a fall run, comprising fifteen to twenty thousand.
>
> "(2) The salmon run to Redding forms not more than half of the total run propagating in the Sacramento River system.
>
> "(3) The annual value to commercial fishermen of the upper Sacramento salmon may vary from $51,000 to $81,000.

"(4) The total values are increased to an unknown degree by values to sportsmen, the fishing trade, recreation, et cetera.

"(5) Two serious hazards to the success of any plan of salvage for salmon were recognized, namely unscreened diversions and 'snagging' on spawning beds." (As summarized by Moffet, 1949)

The Board of Consultants in October 1940 issued a supplemental report entitled Salvage of Salmon on the Upper Sacramento River. Suggestions by the State of California were considered at this time. The suggestions and rulings are presented below as summarized by Moffet (1949).

"State suggestions were: (1) provision for supplementary flow in Stillwater Creek by pumping from Shasta Reservoir, (2) experimental transport of adult salmon above Shasta Dam, (3) provision for expansion of hatchery facilities on Battle Creek, and (4) additional trucks for transport of salmon.

"The board ruled that: (1) the cost of pumping water to Stillwater Creek was excessive, (2) the transport of adult salmon above Shasta Dam might provide some useful information, (3) the possibility of enlarging Battle Creek Hatchery and the construction of a hatchery on Deer Creek should be entertained for the future, (4) the need for seven trucks for salmon transport was justified, (5) additional information should be secured relative to the possibility of providing water from Sacramento River to maintain a permanent flow in Deer Creek, (6) continuous counting of salmon should be done at the lower and middle racks, (7) the suggested drafting of an agreement between the State of California and the Department of the Interior, defining the jurisdiction and the responsibilities of each agency, was not within the power of the board, (8) the Bureau of Reclamation should bear the expense of supplementary measures approved, (9) Keswick Dam should be built as a river flow regulating structure as well as a site for traps, (10) fourteen rearing ponds should be constructed at Battle Creek Hatchery instead of the eight previously recommended, and (11) natural holding ponds in Battle Creek should be used for adult salmon."

The salmon salvage program that was to provide for these first salmon runs was not placed into operation until June 1, 1943; this was due primarily to the delays imposed by wartime conditions.

From 1941 through 1946, 15,972 spring run king salmon were transferred by truck from the Sacramento River to a point 94 miles below Shasta at Deer Creek. Deaths due to dissolved oxygen shortages and excessive temperature occurred at the start of the operation in 1941, but declined to almost nothing by 1946. Successful spawning and egg survival was indicated by fyke net catches of downstream migrant salmon fry. Success in this program was never realized ostensibly due to major improvements needed at Deer Creek. The three improvements reported to be needed at Deer Creek were listed by Moffet (1949):

> "(1) Development of an irrigation water supply from Sacramento River for farms in the drainage which would permit the natural flow of Deer Creek to reach the river, (2) judicious channelization of Deer Creek from Sacramento River to the mouth of its canyon, and (3) removal of all dams and obstructions now impeding movement of fish up and downstream."

Moffet concluded (1949) that "the spring run of salmon is more likely to be perpetuated if left undistributed in the Sacramento River".

Presently, there are no artificial spawning facilities provided for the spring run salmon. Coleman Hatchery water supply is too warm during the spring run hold-over period for successful hatchery operations (Lukin, pers. comm.). The water

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temperature below Keswick Dam is acceptable to maintain spring run king salmon for natural spawning in the main river.

In accordance with the Sacramento River, Battle Creek, Deer Creek plan, fish racks were installed in the main Sacramento River to reduce the number of salmon accumulating below the dam site. The Balls Ferry Rack as described by Hanson, et.al., 1943 was to "be used (1) as a trap, (2) as an aid in the distribution of salmon in the river for natural spawning, and (3) as a barrier for a portion of the salmon to ensure utilization of the riffles below Balls Ferry for spawning". Other river racks were to function in distributing the salmon in the river below Shasta Dam to help prevent overcrowding below the dam. The Deer Creek Rack prevented transferred fish from returning to the Sacramento River and provided counts of the natural-run salmon entering the creek. Neither of the main river racks functioned satisfactorily. They either washed out or were difficult to make fish-tight. By 1946 none of these racks were operable and the project was abandoned (Moffet, 1949).

Presently the Keswick Dam fish trapping installation functions as the only trapping facility for the Coleman National Fish Hatchery at Battle Creek. The trap operates at the same capacity today as when it first was installed (1943). The trap is designed to collect fish at flows under 20,000 cfs, but when flows are greater than 16,000 cfs, the efficiency is greatly reduced (Lukin, pers. comm.).

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In 1971 a U. S. Fish and Wildlife memorandum report proposed a modification to the Keswick fish trapping installation that would enable it to operate at much higher stream flows (55,000 cfs). No action was taken by the Bureau of Reclamtion for construction of this modification. Presently the U. S. Fish and Wildlife Service has a request on file to the Bureau of Reclamation for a trap that would be effective at flows up to 30,000 cfs (Lukin, pers. comm.).

The selected salmon maintenance plan as it was applied to Coleman Hatchery provided the following essential features as described by Needham, Hanson and Parker (1943).

> "a. A hatchery having a capacity of about 58,000,000 eggs or advanced fry, approximately 29,000,000 fingerlings averaging 1-1/2 inches, and such numbers of larger fingerlings as the facilities may provide.
>
> "b. Twenty-eight outdoor ponds, 20 feet x 150 feet, for use as rearing ponds for advanced fry and fingerlings and holding ponds for some of the transferred adult salmon.
>
> "c. A cold storage and ice-manufacturing building.
>
> "d. Combined garage, shop and warehouse.
>
> "e. Dwellings for the operating personnel."

In the years following the initial project report, it was shown by counts taken at Balls Ferry Rack and Keswick Dam that the number of salmon accommodated by the Shasta Maintenance Plan were far in excess of expected numbers. Salmon actually counted amounted to: 41,364 in 1943, 69,481 in 1944, 44,652

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in 1945; and 9,927 in 1946. Estimates of the numbers in the maintenance area above Red Bluff, California were: 144,000 in 1944, 106,000 in 1945, and 96,900 in 1946. (Moffet, 1949)

Minimum in-stream fish releases from Shasta Dam (Keswick) were stated in the Memorandum of Agreement for the Protection and Preservation of Fish and Wildlife Resources in the Sacramento River as Affected by the Operation of Shasta and Keswick Dam ... Between the Department of Fish and Game and the United States, dated April 5, 1960. This agreement was included as a term in State Water Rights License 9956 dated September 21, 1972.

Minimum fish flow releases described in the Water Rights License 9956 of September 21, 1972 are:

"Bypass or release at Keswick Dam at least:

January 1 - February 28	2,600 cfs
March 1 - August 31	2,300 cfs
September 1 - November 30	3,900 cfs
December 1 - December 31	2,600 cfs

"For critical dry calendar year:

January 1 - February 28	2,000 cfs
March 1 - August 31	2,300 cfs
September 1 - November 30	2,800 cfs
December 1 - December 31	2,000 cfs

"During extremely critical conditions, flow may be reduced below 2,000 cfs from December 1 - February 28."

IV. Post-Project

Since construction, the Sacramento River below Shasta Dam has undergone physical changes in temperature, stream flow patterns and bottom sediment composition.

The relatively constant 50°F water withdrawn from the hypolimnion of the reservoir and increased summer flow has produced an aquatic habitat in the Sacramento River more suitable for salmon and trout than what was historically present. However, the dam has blocked the downstream movement of gravel and consequently there is a net loss of spawning gravel below the dam resulting in a deterioration of spawning habitat especially between Keswick Dam and Redding (Coots, pers. comm.).

An ancillary problem that is mitigated by releases from Shasta is the downstream copper pollution from Spring Creek.

During the period of May 1, 1948 to February 28, 1949, the U. S. Fish and Wildlife Service conducted creel censuses below Keswick Dam and found approximately 3,800 rainbow and steelhead trout were taken by 10,900 fishing efforts. The salmon catch, taken in 23,400 fishing efforts, from September 1 through December 31, 1948 was approximately 3,300 king salmon weighing 62,400 pounds. In the following season, approximately 8,000 salmon weighing 136,200 pounds were taken in 43,800 fishing efforts. Present king salmon runs consist of four races of king salmon that have adapted to features in the operation of Shasta Dam (California Department of Fish and Game, 1972). The

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installation of a diversion dam and fish counting station at Red Bluff has facilitated the more accurate enumeration of fish in the river below Shasta. Population calculations in 1973 of the four races (late fall run, winter run, spring run, fall run) are shown in Table 2 as provided by King Salmon Spawning Stocks in California's Central Valley (California Department of Fish and Game, 1974). Times of spawning for the four races are:

Fall run	October - December
Late fall run	January - March
Winter run	April into July
Spring	September or early October

The 1973 population of salmon for the area above Red Bluff is very similar in size to the 1940 project estimates of 96,900 to 144,000 made by Moffet (1949).

Steelhead enter the river in all months but the main run reaches Red Bluff in August, peaks in October and is over sometime in January (California Department of Fish and Game, 1972).

Estimates of king salmon and other migratory fish on the upper Sacramento River are provided by values taken from California Fish and Wildlife Plan (1965) and shown on Table 3.

The warmwater and nongame species present in the river have probably decreased since the project. No information was discovered which analyzed species other than salmonids.

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Table 2

CALCULATION OF 1973 KING SALMON SPAWNING POPULATIONS ABOVE RED BLUFF DIVERSION DAM

Run	Fish passing Red Bluff Diversion Dam in calendar year 1972		Fish passing Red Bluff Diversion Dam in calendar year 1973		Total 1973 potential spawners in run		Sport catch above the dam in 1972 and 1973		Total 1973 spawning population by run
Late-fall run 1972-73	6,309	+	16,701	=	23,010	-	1,229	=	21,781
Winter run 1972-73	127	+	23,952	=	24,079	-	1,428	=	22,651
Spring run 1973	0	+	7,762	=	7,762	-	587	=	7,175
Fall run 1973	0	+	53,891	=	53,891	-	2,136	=	51,755
Late-fall run 1973-74	0		1,268*		0**		29*		0**
TOTALS	6,436		103,574		108,742				103,362

* This run started passing the dam during the week of October 14-22, 1973, and was not completed in 1973. Additional salmon will be added to both the run and sport catch in early 1974.

** Fish in this run spawn in 1974, not 1973.

Table 3

UPPER SACRAMENTO RIVER FISHERY DATA

	King Salmon	Steelhead	Other
Spawning 1/	417,000 in system, 262,000 in main stem above Hamilton City, 150,000 above Red Bluff, 950 in Cow Creek, 23,000 in Battle Creek, 3,500 in Cottonwood Creek.	26,000 in system, 10,000 in main stem above Hamilton City, 500 in Cow Creek, 5,300 in Battle Creek, 1,000 in Cottonwood Creek, some in most tributaries.	Shad from Red Bluff south, striped bass from Hamilton City south, sturgeon from Keswick south.
River Harvest 1/	19,000 is estimated average annual catch.	10,000 is estimated average annual catch.	
River Effort 1/	100,000 angler days.	39,000 angler days is estimated average annual catch.	
Ocean Harvest	Average catch is declining. 800,000 fish in 1964 - 400,000 in 1967. 90 percent of king salmon taken off California are from Sacramento system. 50 percent of all Sacramento salmon are caught off Oregon and Washington.	None.	Sturgeon tagged in the Sacramento enter Oregon and Washington fisheries.
Upstream Mirgration Period	Fall run late August to end of January. Winter run December to mid-April. Spring run late March or mid-July.	Late August through January.	Shad are in Red Bluff area late May to early September. Striped bass adults are in upper river May through September.

1/ Values used in this table are taken from the "California Fish and Wildlife Plan", Vol. III, 1965.

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Release schedules of Shasta Reservoir have changed runoff patterns in the Sacramento River below Shasta Dam. The post-project flow regime shows increased summer and fall flows from the pre-project flow regime. At unimpaired (natural) flows practically all of the annual discharge occurred during the season of heavy rains and snowmelt. Presently, runoff during this period is conserved behind Shasta Dam as shown by the post-project hydrograph (Figure 2).

Copper salts are leached from ore deposits and tailings in the Spring Creek drainage which discharges into Keswick Reservoir. This acidic water laden with copper and zinc has caused several fish kills below Keswick Dam. Runoff in the Spring Creek watershed and reduced outflows from Shasta Dam combined to increase the incidence of copper toxicity below Keswick. During September 26 through 30, 1957, fish mortalities as high as 50,000 fish were recorded (Department of Fish and Game memorandum); the majority being young king salmon between 1.5 and 2.5 inches in length. Many fish killed were those introduced from hatcheries into the reach below Keswick.

In order to reduce the effect of the toxic, heavy metal discharge from Spring Creek, the U. S. Bureau of Reclamation operates the Spring Creek Debris Dam and Reservoir (see Figure 1). The reservoir is operated as a regulating facility to make

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releases of toxic water into Spring Creek that can be safely diluted by Shasta Lake and Spring Creek power plant releases. Thereafter water released from Keswick Reservoir is of sufficient quality to be safe for fish in the Sacramento River. The objective in the operation of Spring Creek Debris Reservoir is to maintain as empty a reservoir as possible to capture and store peak flood flows from the Spring Creek watershed. Dilution graphs, to avoid toxic conditions to fish, furnished by the California Department of Fish and Game are then used to determine the rate of release of dilution water from the project. Consideration is also given to all other tributary flows to Keswick Reservoir containing copper salts (U. S. Bureau of Reclamation, 1975). Presently fish kills occur when Spring Creek is allowed to spill at the wrong time (Department of Fish and Game, 1972). None have been as severe as the 1957 fish kill, although more recent kills have occurred.

Below Keswick Dam sediment conditions in the Sacramento River have been affected by the Shasta-Keswick unit. Under natural circumstances, bedload movement grades, cleans and replaces gravel in the river's bed and thus in spawning riffles. Shasta and Keswick Dam block the source of new gravel and the stream channel is gradually eroding to bedrock formations. This succession in bed type was observed below Keswick by the Department of Fish and Game in 1972.

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The Coleman fish hatchery has functioned well to mitigate the loss of spawning grounds above Keswick.

In addition to Coleman Hatchery, the U. S. Fish and Wildlife Service also operates a spawning channel on the Tehama-Colusa Irrigation Canal, at the Red Bluff Diversion Dam constructed in 1966. The spawning channels were first planned in 1965 but were not completed until 1971. Since completion, fall run salmon have been diverted out of a fish ladder at the irrigation dam to three spawning channels. The channels will ultimately handle 80 to 100 million eggs (Schoeneman, pers. comm.). In the fall of 1973, 2,491 fall run salmon were diverted to the spawning channels and in late spring of 1974, approximately 4,700,000 juvenile salmon were released into the Sacramento River.

Coleman Hatchery has a 58,000,000 egg capacity, but normally does not receive more than 20 million eggs from the fall runs (Lukin, pers. comm.). There are 58 rearing ponds at the hatchery providing a rearing capacity of 15 million fish at approximately 3 inches in size (Lukin, pers. comm.).

Water releases from Shasta have effects on fish and wildlife extending downstream into San Francisco Bay. These effects are interwoven with other water project releases and diversions which overall have significant effects on striped bass, sturgeon, shad, warmwater game fish, nongame fish, waterfowl and marsh communities as well as salmon and steelhead.

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Before other projects were constructed, Shasta retarded the historical incursion of saline water into the Sacramento-San Joaquin Delta. Reviews of these effects can be found in the numerous reports of the California Department of Fish and Game Delta Study.

V. Conclusion

The operation of the Shasta-Keswick project in conjunction with other units of the Central Valley Project, such as the Trinity-Lewiston project, has increased the annual instream flow in the Sacramento River as compared to pre-project conditions (see Figure 2). The mean monthly flows as shown on the post-project hydrograph (Figure 2) are far in excess of the minimum instream flow reservation which was established for fish 15 years after the initial operation of the project. Flow releases from Shasta-Keswick have exceeded the minimum instream flow reservation because of the magnitude of downstream water demands for irrigation, navigation and salinity control.

The reduction of releases during the spring storage phase has reduced the magnitude of spring runoff in the Sacramento River which was diluting toxic runoff (copper) from Spring Creek which drains into the Keswick Reservoir. Fish kills have been associated with the alteration of wet season streamflow patterns; however, the present coordinated regulation of

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discharges from Shasta Dam with runoff in the Spring Creek watershed have helped solve the toxicity problem.

The maintenance of fall and winter king salmon runs in the Upper Sacramento River has been successful as shown by comparisons of 1973 and 1939 salmon counts. These king salmon population estimates tend to indicate that water releases from Shasta along with fish propagation and the adequate screening of diversions have been a major factor in the maintenance of king salmon. Salmon populations presently use spawning riffles below Keswick Dam. The lack of a significant influx of gravel to maintain these riffles poses a serious threat to the maintenance of the present levels of the natural spawning. The Tehama-Colusa spawning facility may compensate for this loss.

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